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Impact of Fire on Concrete and Concrete Structures

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ABSTRACT

Concrete structures are frequently exposed to fire. This imposes a thermal shock depending on the fire. Contrary to common belief, it is not only the maximum temperature that is important but also the rate at which temperature rises (e.g. the heating rate). This topic gives a comprehensive knowledge on the overall strategy for the restoration of fire damaged buildings and also presents a critical appraisal of the assessment procedures by different non destructive techniques, specifications and execution of repair techniques With the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire damaged structures has become a topical interest.

The general conclusion is that majority of fire damaged RCC structures are repairable. But the impact of elevated temperature above 900°C on the RCC structures was observed that there is significant reduction in strength of concrete and ductility of bars when rapidly cooled by quenching.

1. INTRODUCTION

Fire is one of the natural hazards that attack the building constructions, subjecting concrete to a higher temperature (e. g., due to accidental fire etc.) leads to severe deterioration and it undergoes a number of transformations, thereby causing reduction in strength, durability and increases the tendency of shrinkage & structural cracking.

The deterioration of mechanical properties such as compressive strength would depend upon the type of constituents used, the physico-chemical reactions that take place during heating and the maximum temperature reached. Therefore effective design of concrete against fire need to consider both explosive spalling and loss of mechanical properties.

If the bottom side of the slab is subjected to fire, the strength of the concrete and the reinforcing steel will decrease as the temperature increase. However, it can take up to three hours for the heat to penetrate through the concrete cover to the steel reinforcement. As the strength of the steel reinforcement decreases, the moment capacity of the slab decreases. When the moment capacity of the slab is reduced to the magnitude of the moment caused by the applied load, flexural collapse will occur. It is important to point out that duration of fire until the reinforcing steel reaches the critical strength depends on the protection to the reinforcement provided by the concrete cover.

Fig.1.1: Fire Damaged Concrete Surface

Fig 1.2: Fire Damaged Building

1.2 Objective

In general this investigation was carried out to study the Impact of Fire on Concrete & Concrete Structures. In more specific terms this research was conducted to achieve the following objectives:-

- To study the assessment and repair methods of the fire damaged concrete surface.
- To study the changes in the mechanical properties of concrete and steel corresponding to high temperature at the different rate of heating.
- To study the effects of different cooling methods on the mechanical properties of fire-damaged concrete and steel.
- To study the effect of Spalling on strength, stiffness and durability of Concrete.
- To compare the impact of fire on properties of high strength concrete and normal concrete.

1.3 Need of the Study

- To make concrete surface functionally feasible (at some extent) after damaged due to fire incidents.
- To make assessment and repairs of fire damaged surface.
- To re-gaining the strength of RCC surfaces(by using repairs techniques) which are damaged due to changes in the mechanical properties with the effect high temperature related to the rate of heating.
- To study the behavioural changes in concrete and steel due to fire .
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2. EXPERIMENTAL STUDY

2.1 Study of Concrete Specimen

- The experimental program consists of casting and testing concrete cubes of M20 Grade and M30 Grade at different temperatures with different cooling Methods.
- The Concrete cubes of size 150mm x 150mm x 150mm were casted and heated to 100°,300°,600°,900° centigrade in Electric Furnace.
- A total number of 78 cubes were casted with 39 cubes of M20 grade and 39 cubes of M30 grade of concrete.
- The Compressive Strength were tested at normal room temperature condition for 3 cubes of each grade of concrete on Compression Testing Machine and then comparing these cubes which were exposed to different temperature.
- The 9 cubes of each grade were exposed to 100°C for 60 minutes in Electric Furnace and three specimens were tested immediately at hot state, three specimens were tested by air cooling for one hour and three specimens were tested after quenching in water for one hour.
- Similar testing was conducted on remaining cubes of each concrete grade exposed to 300°C, 600°C, and 900°C respectively.

Fig.2.1: Concrete Cubes

Fig.2.2: Concrete cubes of M20 grade

Fig.2.3: Concrete cubes of M30 grade

2.2 Preparation of Concrete Specimen

- All the materials i.e. Cement, Fine Aggregates, Coarse Aggregate and Water with proportion 1:1.5:3 (Cement:Sand:Aggregate) for M20 grade were mixed thoroughly on plane non porous surface.
- Similarly M30 grade of Concrete were prepared as per Mix Proportion.
- The moulds of 150mm x 150mm x 150mm dimensions were prepared to cast the concrete cubes of M20 grade and M30 grade by oiling the inner sides of moulds.
- The matrix were poured into the moulds with each corner properly filled and well tamping with tamping rod to prevent any voids and honeycombing.
- The moulds were kept for 24 hours at room temperature.
- The cubes were then taken out from the moulds and kept in the water tank for 28 days for curing.
- After 28 days the cubes were taken out from the tank and 3 cubes of each grade were tested for compressive strength on Compression Testing Machine.
- Similarly remaining cubes of each concrete grade were tested for different temperatures and different cooling Methods.

Fig.2.4 Testing of M20 grade of Concrete cube on UTM

Fig.2.5 Testing of M30 grade of Concrete cube on UTM

2.3 Study of Steel Specimen

- The specimens used for testing were Shri TMT bar of 10mm diameter.
- 27 bars were cut to 40 cm size.
- 3 Specimens were tested for the mechanical properties using UTM before heating (at normal temperature).

- 6 specimens were heated in the electrical furnace at 100°C for an hour without any disturbance.
- After heating, 3 specimens were quenched in water for rapid cooling and the other 3 were kept aside for normal air cooling at atmospheric temperature.
- These specimens later were tested for mechanical properties .
- Similarly remaining specimens were tested for 300°, 600° and 900°C respectively.

Fig.2.6 Tensile testing of Reinforcement Steel

2.4 Equipment used for Heating the Specimen

- **Electric Furnace**

An electric furnace was used to heat the specimens. The maximum attainable temperature in this furnace was 1150°C. The inner depth of the furnace was 1000mm.

Fig 2.7: Electric Furnace

3. RESULTS AND OBSERVATIONS

After the test it has observed that, both Normal and High strength concrete specimens when subjected to elevated temperatures, small surface cracks were observed. The magnitude and extent of cracks were somewhat negligible up to 300°C. Magnitude and extent of cracks increased for both normal and high strength concrete as the temperature increased above 400°C. However, more cracks were noticed in case of high strength concrete compared to normal concrete. At high temperatures of exposure, the sharp edges of the specimen become blunt. Colour change (light pink) of surface of the specimen has been observed at 600°C. The concrete after exposure to 900°C was found to be red hot and concrete looked slightly pink even after cooling.

3.1 Effect of Elevated Temperatures on Grades of Concrete:

The results clearly indicate that there is a reduction in compressive strength with temperatures of exposure. The reduction in compressive strength with temperature occurred for both normal concrete and high strength concrete. The average loss in strength in M20 grade concrete is about 7.4%, 12%, 19.8%, and 43.5% at 100°C, 300°C, 600°C, and 900°C respectively. In case of HSC (M30 grade) the average compressive strength loss is observed to be 18.6%, 30.6%, 50.7%, and 69.3% at 100°C, 300°C, 600°C, and 900°C respectively. In general the high strength concrete (HSC) mixes normally have high paste to aggregate content compared to normal strength. Hence more loss of strength in HSC may be due to occurrence of micro cracking because of thermal incompatibility of hardened cement past and aggregates.

3.2 Effect of Cooling Methods on Compressive Strength of Concrete:

Specimen were tested at room temperature in three Methods viz., air Cooling, water quenching and hot condition, The compressive strength results presented in table reveals that air cooling of specimens resulted in more loss of strength compared to that of water quenching and hot condition. In case of specimens of normal concrete (M20) subjected to 600°C the percent loss in strength observed to be 14.4%, 17.6%, and 27.2% for the cooling regime water quenching, air cooling and hot state respectively. In case of normal concrete (M30) subjected to 600°C the percent loss in strength observed to be 29.6%, 45.6%, and 62.2% for the cooling regime hot state, water quenching and air cooling respectively. However again at high temperatures of exposure the difference in percent loss in strength between different cooling regime reduces, for example for M30 grade subjected to 900°C has shown percent strength loss to be 62.2%, 68.5%, and 71.2% for the cooling regime hot state, water quenching and air cooling respectively and that of M20 grade it was 38.9%, 44.8% and 54.8% for cooling regime hot state, water quenching and air cooling respectively.

Table 3.1: Volume of materials for 3 Cubes of M20 Concrete Grade

	Cement	Fine Aggregate	Coarse Aggregate	Water
Volume	4.05 Kg	6.08 Kg	12.16 Kg	1.83 litre
Proportion	1	1.5	3	0.45

Table 3.2: Volume of materials for 1 Cube of M30 Concrete Grade for trial mix 1

	Cement	Fine Aggregate	Coarse Aggregate	Water
Volume	1.6 Kg	2.53 Kg	3.22 Kg	0.64 litre
Proportion	1	1.58	2.01	0.4

Table 3.3: Volume of materials for 1 Cube of M30 Concrete Grade for trial mix 2

	Cement	Fine Aggregate	Coarse Aggregate	Water
Volume	1.75 Kg	2.45 Kg	3.08 Kg	0.63 litre
Proportion	1	1.4	1.76	0.36

Table 3.4: Volume of materials for 1 Cube of M30 Concrete Grade for trial mix 3

	Cement	Fine Aggregate	Coarse Aggregate	Water
Volume	1.45 Kg	2.58 Kg	3.26 kg	0.64 litre
Proportion	1	1.78	2.25	0.44

Table 3.5: Compressive Strength of Concrete Specimen In N/mm^2

Sr. No.	Temperature (^{o}C)	Air Cooling		Water Quenching		Hot Condition	
		M20	M30	M20	M30	M20	M30
1	Room Temperature(27^{0}C)	24	35.6	22.7	32	23.4	34
2	100 ^{o}C	25.6	31.9	21.4	28.5	24.2	29
3	300 ^{o}C	22	28	23.2	26.8	21.3	29.7
4	600 ^{o}C	19.5	22.4	17.9	20.2	20.2	18.9
5	900 ^{o}C	13.7	13.5	18.2	16	11.6	19.3

Table3.6: Properties of Steel for Normal Temperature

Sr. No	Temperature (^{o}C)	Ultimate Load(KN)	Tensile Strength (KN/mm^2)	Yield Stress (KN/mm^2)	Elongation (%)
1	Room Temperature (27^{0}C)	54.20	0.694	0.662	22

Table 3.7: Properties of steel for Air cooling condition

Sr. No.	Temperature (^{o}C)	Ultimate Load(KN)	Tensile Strength (KN/mm^2)	Yield Stress (KN/mm^2)	Elongation (%)
1	100 ^{o}C	50.50	0.677	0.610	20
2	300 ^{o}C	50.60	0.693	0.617	18
3	600 ^{o}C	48.55	0.654	0.583	10
4	900 ^{o}C	33.05	0.443	0.337	14

Table 3.8: Properties of steel for Water Quenching cooling condition

Sr. No.	Temperature (°C)	Ultimate Load(KN)	Tensile Strength (KN/mm^2)	Yield Stress (KN/mm^2)	Elongation (%)
1	100 °C	49.70	0.623	0.653	18.2
2	300 °C	51.62	0.638	0.622	17
3	600 °C	54.23	0.698	0.566	11.4
4	900 °C	48.12	0.512	0.394	12.9

Fig.3.1: Color changes of concrete cube at 900^{0}C

Fig.3.2: Heating of Concrete cube at 100^{0}C

Fig.3.3: Heating of Concrete cube at 300^{0}C

Fig.3.4: Heating of Concrete cube at 600^{0}C

Fig.3.5: Heating of Concrete cube at 900^{0}C

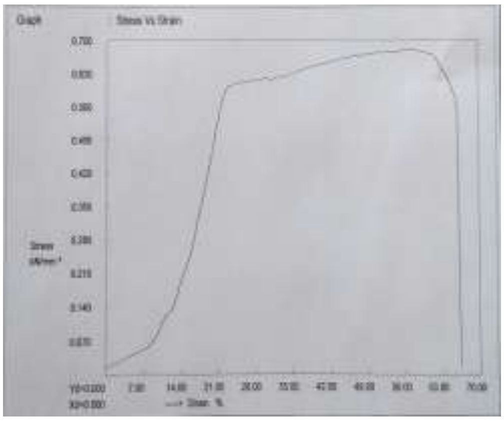

Fig.3.6: Stress-Strain graph of Reinforcement Steel for 100^{0}C

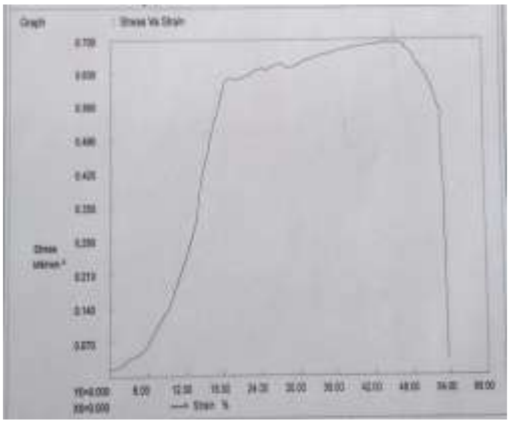

Fig.3.7: Stress-Strain graph of Reinforcement Steel for 300^{0}C

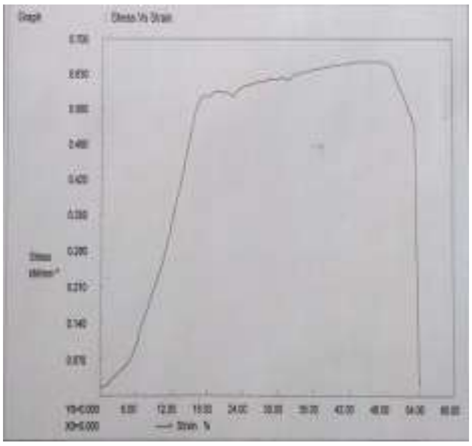

Fig.3.8: Stress-Strain graph of Reinforcement Steel for 600^{0}C

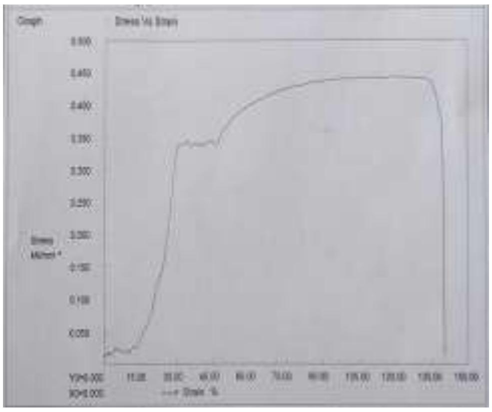

Fig.3.9: Stress-Strain graph of Reinforcement Steel for 900^{0}C

4. CONCLUSION

- From the above study it can be concluded that, mechanical properties of concrete are influenced by heating.
- The compressive strength varies not only from concrete to concrete depending on its constituents (e.g. aggregate and cement blend) but also on other factors such as external loading, heating and moisture conditions.
- Strength of concrete decreased with increase in temperature.
- The loss in compressive strength at elevated temperature is more in case of High strength concrete compared to Normal strength concrete.
- Decrease in compressive strength is more at high temperatures of 900°C.
- Testing after air cooling of specimens resulted in more loss of strength followed by testing after water quenching and testing at hot condition.
- Rapid heating during fire could induce explosive spalling with serious consequences to structure.
- The test results indicated more loss of hardness and increased risk of spalling in case of High Strength Concrete than Normal Concrete at high temperatures.
- Studying the characteristic changes in the mechanical properties of the bars by tensile strength testing using Universal Testing Machine shows that the increase in ultimate load and decrease in percentage elongation of the specimen which mean that there is significant decrease in ductility of the specimen.

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